MOBILE ENVIRONMENTAL LABS

Imagine a site, far from the nearest city, without power, without easy access, without anything but an unpleasant variety of environmental contaminants. Traditional approaches to studying such problems involve collecting samples for off-site analysis but this takes time and is expensive, and there is the potential for sample degradation. Now, thanks to systems designed and built by groups headed by researchers in the German Federal State of Schleswig-Holstein and the U.S. Army, a new approach involves sending the lab to the sample, rather than the other way around.

The Environmental Analysis Van

For a variety of reasons, environmental medicine is a controversial subject in Germany. In a paper entitled *Activities of an Environmental Analysis Van in the German Federal State of Schleswig-Holstein,* to be published in the August 1997 issue of *EHP*, authors Anke Pröhl, Klaus-Peter Böge, and Carsten Alsen-Hinrichs of the Institut für Toxikologie state, "Although some scientists deny the need for environmental medicine in addition to occupational medicine, an increasing demand for environmental medicine has been observed over the last years in Germany. Physicians are confronted with patients suffering from diffuse symptoms [that] they are not able to explain by conventional differential diagnosis."

Relatively recent studies in Germany suggest that the use of wood preservatives in homes may cause neuropsychological and respiratory disorders; until 1979, wood preservatives used in Germany contained pentachlorophenol and hexachlorocyclohexane, pesticides known to be neurotoxic. These and other studies have begun to create a demand for expertise in environmental medicine. In 1992, a cooperative effort was begun between Böge and the Union of Physicians of Schleswig-Holstein, which led to the creation of the Environmental Analysis Van (EAV).

The EAV, according to Pröhl, was created "to help physicians and their patients who suffered from symptoms of illness they suspected to be related to exposure to indoor xenobiotics." Illnesses resulting from exposure to indoor environmental agents are estimated at about 2% of all illnesses in Germany, Pröhl says, "though some scientists are of the opinion that there is no such thing as adverse health effects from indoor pollutants. On the other hand, there are about 20,000 people organized in an association of people who [claim to have been] harmed by [exposure to] wood preservatives. As it is not well known in the German medical profession that indoor pollutants [can] cause adverse health effects, people are not treated accordingly . . . As a result, these kinds of diseases are very expensive, as these patients undergo costly diagnostics but the cause of the symptoms of their illness is not found."

According to Pröhl, the Union of Physicians of Schleswig-Holstein decided that human monitoring alone was not sufficient to address illnesses related to indoor exposures because of the limited knowledge of the effects of concentrations in human bodily fluids. Environmental monitoring of the indoor site was deemed necessary, thus the creation of the EAV to perform such on-site analysis.

The first EAV was built in 1992 at a cost of about 170,000DM (about $120,000). The size of a minivan, the EAV was designed to allow researchers to collect and analyze samples of air, water, and other contaminated materials at indoor sites. Equipment in the EAV includes a photometer for analysis of formaldehyde, special borers and other devices for taking samples of wood materials, active and passive sampling devices to detect asbestos and volatile organic compounds, and electric thermo-hygrometers to quantify dampness and general room climate.

Researchers using the EAV can measure on-site concentrations of substances such as formaldehyde (outgassed by pressed wood used in furniture and building materials, particularly from mobile or prefabricated houses) and carbon dioxide and nitrogen oxide (which support growth of molds and fungi). Analysis of contaminants including biocides used in wood and carpet preservatives, asbestos used in insulation materials and storage heaters, and volatile organic compounds outgassed by cleaning solvents, paints, and lacquers can be performed at off-site laboratories using samples collected by researchers in the EAV. Pröhl says such a system allows "cooperation between the physician, who has knowledge of the diagnosis and treatment of patients with adverse health effects but perhaps not of indoor xenobiotics and their analysis, and the environmental engineer, who understands xenobiotics but has limited or no knowledge concerning the treatment of their effects."

Between July 1993 and December 1995, the EAV conducted 1,793 site inspections, with xenobiotic analysis and subsequent advising offered in 1,318 of those cases. An EAV analysis can be initiated by patients or physicians who suspect a link between an individual's health problems and indoor contamination, or by a business with employee health problems it suspects may be traceable to so-called "sick building syndrome." Of the 1,793 site inspections, about 60% were the result of a referral by a physician who suspected indoor pollutants as the cause of illness.

During an inspection, an environmental engineer inspects the building from basement to attic and enters into a database information such as whether there is a record of biocide use at the site, the time of last remodeling, products used in the remodeling including new furniture, water quality at the site, age of the building, treatment of wood, and the location of any nearby industrial sites.

According to Pröhl, each EAV operator is required to extensively document the results of an inspection including the presence of contaminants such as biocides, solvents, and tobacco smoke. "The advantage of the EAV," says Pröhl, "lies in the possibility of a follow-up on clients of the EAV who were exposed to a particular kind of indoor xenobiotic, because the [contaminants] can be investigated and controlled." He continues, "An experienced environmental engineer is in most cases able to point out possible or probable sources of indoor contaminants. If a source is rather obvious—visible molds, strong paint smells—analysis of the xenobiotics is sometimes unnecessary, and the environmental engineer can advise steps to minimize or halt exposure. If exposure is not as obvious, the engineer advises analysis of concentrations of certain xenobiotics, and the results of the inspection and analysis are documented in a data sheet that can be taken to a physician or environmental medicine specialist who can suggest further action."

Says Pröhl, "Environmental analysis and the study of indoor xenobiotics is a relatively young field in this country, and since we're often dealing with contaminants in low concentrations but exposures of many years, the database assembled by the EAV can be the basis of scientific investigation of the effects of chronic exposure to low concentrations of these substances."

Currently the database consists of three parts: documentation of the activities of the EAV, documentation of patients with symptoms traceable to environmental contamination who were referred to the EAV, and ongoing documentation of 466 patients suffering from a variety of neurological disorders believed to be caused by exposure to environmental toxins.

Field Integrated Environmental Assessment Laboratories

In the United States, efforts to develop mobile analysis units have focused more on the outdoor environment than the indoor. The U.S. Department of Defense (DoD) has generated an estimated 400–800 hazardous waste sites across the United States—sites that will require $5–10 billion for remediation over the next 10 years. The DoD also operates an estimated 500–700 domestic and 100–200 industrial wastewater plants across the country. Although environmentalists and government officials toss around numbers for the cost of cleaning up these sites, Hank Gardner, director of the U.S. Army Center for Environmental Health Research (USACEHR), part of the U.S. Army Medical Research and Materiel Command in Fort Detrick, Maryland, points out, "You don't really know how much it's going to cost to clean up one of these sites until you know what it's contaminated with, the extent of the contamination, and the complexity of the mixture with which it's contaminated."

One approach to this problem taken by the USACEHR, in collaboration with Engineering Computer Optecnomics, Inc. (ECO) of Annapolis, Maryland, and others, has been to design and build a complex of transportable laboratories that can be taken directly to a contaminated site. The laboratories can function there independently for days to months while performing a wide range of tests to determine the type and extent of contamination at the site.

The goal, says Gardner, "is to look at complex mixtures in the environment, and try to get a handle on their health effects. These mobile labs allow us to adopt a 'canary in the mine' approach, where we do studies and place control animals directly into the environmental situation in order to gain a more complete and accurate understanding of what kinds of problems we might be dealing with, and what their environmental consequences might be."

Officially known as Field Integrated Environmental Assessment Laboratories, the $2 million complex relies primarily on analysis of aquatic organisms, which are

Jens-Marten Martensen

On-site analysis. Environmental engineer Klaus-Peter Böge tests for concentrations of formaldehyde.

Jens-Marten Martensen

To the rescue. Known in Germany as an environmental ambulance, the EAV is dispatched to sites of possible contamination.

generally more sensitive to contamination than large mammals. Test animals include protozoa, bluegill, fathead minnows, medaka, and embryonic frogs. The body of knowledge about these animals, as well as what is found on-site, is extrapolated into predictions of the potential impact of contaminants on human health.

"It's an interesting and somewhat controversial issue," admits Gardner. "We're currently working through an interagency agreement with the NIEHS and others to try to address the issues and protocols involved in extrapolating from one species to another, but there's a great deal of biological knowledge about these animals and their pathology, and there's a lot of biological support for the extrapolations we do make. This laboratory will help further develop the scientific foundation for those extrapolations."

The complex consists of three modules, each a 48-foot-long, 35,000-pound trailer designed to function both separately and as part of a network, and to be transportable by a typical tractor rig. The three trailers house a chemical analysis research lab, an aquatic biomonitoring research lab, and a research support module—a kind of "command post" with desks, office space, and an advanced computer system that allows operators to constantly monitor all the experiments and studies in the other modules. Each trailer is equipped with its own power supply, HVAC system, fuel tank, and wastewater holding tank, as well as hydraulic leveling legs sufficient to deal with almost any terrain.

Chemical Analysis Research Lab. This lab is physically divided into two work spaces. The analytical preparation room is equipped with a fume hood, a sink, acid and solvent storage cabinets, and a drying oven. The analytical instrumentation room includes a purge-and-trap gas chromatograph–mass spectrometer for analysis of volatiles like chloroform and trichloroethane; a high-performance liquid chromatograph for detecting explosives like TNT and C4, as well as by-products that can't go through a gas chromatograph; and an inductively coupled plasma spectrometer for metals analysis. All of these instruments are linked directly to computers for test condition control and data storage. A third, smaller room provides compressed gas storage and is equipped with a specially designed overhead crane to facilitate resupply of the cylinders.

The inductively coupled plasma spectrometer, according to Alan Rosencrance, a chemist with the USACEHR, is one of a new generation of devices at the heart of the mobile lab's enhanced capabilities. "This spectrometer," he explains, "aspirates a sample through an argon plasma flame and yields an emission spectrum, which allows for multi-element analysis. That's a tremendous advantage . . . Using this, we can test for metals like lead, arsenic, and selenium—up to 30 different common environmental contaminants. This spectrometer has a sensitivity in the parts per billion range. [Eventually,] we'll be upgrading to the new inductively coupled plasma mass spectrometer, which has a sensitivity in the parts per trillion range."

The microwave oven sample preparation system bypasses traditional methods involving large amounts of nitric acid and long heating times. "With this new system," says Rosencrance, "we can put a small sample into a sealed vessel, along with a small amount of nitric acid, hit it with a strong microwave source for 20 minutes, and we're done. We can do multiple samples all at once and reduce the time involved, fume exposure, and the total volume of nitric acid we have to transport and deal with."

Michelle Lorah, a hydrologist with the U.S. Geological Survey (USGS), is project leader for a group studying groundwater contamination and bioremediation near Aberdeen Proving Ground, Maryland, where the lab is currently stationed. "We're looking at volatile organic compounds," says Lorah, "as well as things like methane, ethane, and ethylene. Additionally, we're studying substances like trichloroethane and carbon tetrachloride—substances common in many hazardous materials sites, as well as most landfills. The lab has proven invaluable in this study."

Lorah continues, "Our USGS district office here doesn't have a detailed lab facility, so under normal circumstances we'd have to send samples to a facility in Denver or some other contract lab and it might be three months before we get the results back. This facility has allowed us to do on-site analysis, and, since we're dealing with [many] substances which have short containment times, the lab has enabled us to do research we couldn't otherwise do."

Aquatic Biomonitoring Research Lab. This facility consists of three work rooms. The analytical/operational control room contains the analytical equipment necessary to support the experiments, computers for data recording, and operational controls for all systems. The main dilutor room contains two banks of test animal tanks. The ventilatory monitor room contains another set of test tanks, as well as equipment to aerate, filter, and control the temperature of the test waters.

The aquatic lab allows for on-site traditional ecological assays for acute toxicity, as well as tests like the Ames test and Chinese hamster ovary chromosomal aberration assay. New tests being developed include a nonmammalian vertebrate cancer assessment model and the Frog Embryo Teratogenicity Assay–Xenopus (FETAX) to assist in the determination of potential developmental toxicants.

"We can also do on-site fish carcinogenicity tests on lab-hatched medaka," says Gardner, "taking animals that haven't been exposed to any carcinogen and exposing them to varying concentrations of the water or wastewater being studied. Or, we can 'pre-expose' the fish to low levels of a known carcinogen, thus helping determine the presence of both 'complete' carcinogens and what are called 'tumor promoters.' We're still working out some of the exposure protocols, but there's a great deal known about the normal history and biological responses of these test animals, so they're allowing us to build a larger and larger database for further study."

Edward Little, chief of the ecology branch of the Midwest Science Center at the USGS in Columbia, Missouri, was part of a 1996 study of groundwater contamination at Aberdeen Proving Ground. "We did toxicology tests and respiration monitoring studies," Little says, "and the biology trailer

Suggested Reading

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allowed us to do real-time studies that wouldn't have been possible with more traditional methods . . . [Traditionally], your options are to either isolate a contaminant and then reformulate exposure at a lab or to collect a quantity of water in the field and bring it to the lab. Testing fish requires a tremendous amount of water, far more than is practical to bring back from the field, and we were also looking at volatiles where any extended period of time could dramatically alter the chemical characteristics of the water. There is a tremendous amount of technology crammed into a relatively small space, and putting these trailers together required some innovative problem solving."

The most challenging design issues, according to ECO Vice President Stan Finger, centered around vibration and temperature control. "We had a temperature tolerance of plus or minus 1°C in both the air and water in these trailers, no matter what the external temperature, so we had to provide a sophisticated temperature and air flow system backed by a large power generator, and we had to do it without allowing any vibration through the system. Some of these experiments deal with the electronic measurement of very small signals, so you have to be absolutely sure your measurements aren't confounded by the slightest trace of background vibration. We also had to provide uninterruptable onboard power, so that there couldn't be any data loss through power fluctuation or failure, and we had to put it all in a setting that was as 'human friendly' as possible."

The Benefits

On-site analysis provides several benefits over more traditional methods, according to Rosencrance. "Time is one big factor," he points out. "Typically, when we're dealing with a contract lab, there's a 3–4 week turnaround time. Additionally, we frequently need to send large volumes of samples, and we're dealing with some potentially quite hazardous material, which makes transportation a risky business."

Another problem that arises involves sample degradation. If the sample isn't analyzed within an appropriate period of time, it can lead to breakdown of the sample constituents, which can, in turn, impact the accuracy of the testing.

Field testing, believes Gardner, "yields a much more complete, more accurate picture. You're frequently dealing with a large number of chemical contaminants—a mix that's almost impossible to duplicate in a lab [because] some components [have] incomplete or even nonexistent toxicological data. And then, if you're not [working in] real time in the field, a second set of problems arises when you have to decide which chemicals are at dangerous levels, what their effects can be, and what the additional effect of the combination might be."


USACEHR


USACEHR

Tester trailers. Mobile environmental labs (bottom) include equipment such as an aquatic lab (top), which allows on-site ecological assays for acute toxicity.

The significance of all this, says Bill Mauck, director of the Midwest Science Center, "is that this type of system is really the only way to get a broad-based measurement of the overall hazard confronting an area. Chemical analysis is valuable when you know exactly what you're looking for, but the beauty of aquatic biology is that you don't have to know. Fish don't care what the contaminant is, they only know that something's bothering them, and that's our 'canary in the mine,' our early warning system."

The DoD trailers are not yet a "one-stop shop" for environmental analyses, but it may be a possibility. One thing the trailers cannot do, for example, is radiation analysis (although ECO has designed and built trailers for the Department of Energy specifically for that purpose). "Radiological analysis is also a future possibility," says Gardner, "especially as we're looking at possibly offering this technology for use in Eastern Europe. There, we'd potentially be dealing with a variety of contaminants—some chemical, some radiological, and some in combination. It would involve further modification of the trailers and their instrumentation, but it's certainly within our technological capabilities."

"We also are not doing a lot of airborne analysis," Gardner adds. "This isn't currently much of an issue, however, because most of the site contamination we're dealing with is soil or groundwater, rather than airborne, but we are building up to that capability." Airborne and radiological capabilities would be invaluable, agrees Jim Petty of the Midwest Science Center, but, he says, "I'd also like to see them develop a more advanced video monitoring system to study changes in fish behavior as they're exposed to different levels of contamination."

Although the mobile labs were designed for military applications, the application to civilian environmental problems is tremendous. For example, Gardner says, "There's one test we do that involves exposing a bluegill to contaminated water and monitoring its breathing and movement to assess its reaction to an effluent. Something like this could give a wastewater plant operator a way to know the quality of the water his plant is pumping out, and because it's all electronic, you could set up a system to control the flow, start the samplers, shut off the discharge, and alert the staff in the event of a problem."

"I think these trailers would be invaluable in many settings," says Petty. "They could be used at an EPA Superfund site, a national park, in an urban setting, in any application where there's concern about contamination." Other U.S. sites for the trailers are currently under consideration, contingent on additional funding.

Gardner sees the mobile labs as part of a biological monitoring network, a system that could give a real-time assessment of national, or even international, environmental quality. By looking at contamination before and after remediation, he says, the systems can help assess the efficacy of remediation efforts and suggest future strategies.

"Almost 40 years ago," says Gardner, "Rachel Carson wrote about environmental contaminants, their potential impact on humans, and how we could forewarn ourselves by studying the living things in the world around us. We need an approach that validates the concept of extrapolating from animals to humans, and lab networks like this [will] help us further explore our interrelatedness with the environment."

Lance Frazer